Infrared Eye: prototype 2

Benoît Ricard
Paul Chevrette
Mario Pichette
DRDC-RDDC Valcartier

Defence Research & Development Canada - Valcartier

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Authors

Benoît Ricard, Paul Chevrette, Mario Pichette

Approved by

G. Otis

Section Head

Approved for release by

G. Otis

Section Head

Abstract

The Infrared (IR) Eye was developed with support from the National Search and Rescue Secretariat (NSS), in view of improving the efficiency of airborne search-and-rescue operations. The IR Eye concept is based on the human eye and uses simultaneously two fields of view to optimize area coverage and detection capability. It integrates two cameras: the first camera, with a wide field of view of 40°, is used for search and detection while the second one has a narrower field of view of 10°, giving the higher resolution required for identification; this narrower field is mobile within the wide field and slaved to the operator's line of sight by means of an eye-tracking system. The images from both cameras are fused and shown simultaneously on a high resolution CRT display unit, interfaced with the eye-tracking unit in order to optimize the human-machine interface. The IR Eye system was flight tested using the Advanced System Research Aircraft (Bell 412 helicopter) from the Flight Research Laboratory of the National Research Council of Canada. This memorandum describes the prototype and its design approach, presents some results of the flight tests, indicates the strengths and deficiencies of the system, and suggests future improvements for an advanced system.

Résumé

L'Oeil Infrarouge (IR) a été mis au point grâce au soutien du Secrétariat national de recherche et sauvetage (SNRS). pour améliorer l'efficacité des opérations aériennes de recherche et sauvetage. Le concept de l'Oeil IR est calqué sur l'œil humain et utilise simultanément deux champs visuels afin d'optimiser l'étendue de la surface couverte et la capacité de détection. Deux caméras sont intégrées : la première est utilisée pour la recherche et la détection, avec un champ de 40°, tandis que la seconde possède un champ de 10°, plus étroit pour une plus grande résolution nécessaire à l'identification; ce champ plus étroit est mobile dans le cadre du champ large et asservi à la direction de regard de l'opérateur sur l'affichage au moyen d'un oculomètre. Les images des deux caméras sont fusionnées l'une dans l'autre et affichées simultanément sur un écran CRT à haute résolution, interfacé avec l'oculomètre pour une interaction humain-machine optimale. L'Oeil IR a subi un premier test en vol à bord de l'hélicoptère Bell 412 de recherche sur les systèmes évolués du Laboratoire de recherche en vol du Conseil national de recherches Canada. Ce mémorandum décrit le prototype et la démarche suivie pour sa conception, présente quelques résultats du test en vol, souligne ses forces et ses faiblesses, et suggère des améliorations pour un futur système plus avancé.

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Executive summary

The purpose of Infrared Eye is to improve night and adverse weather capabilities during general surveillance and search-and-rescue (SAR) missions, not only by using infrared (IR) or thermal imagers, but by providing a system which is better adapted to mission and user's requirements. To conduct such missions efficiently, particularly in airborne scenarios, a wide area coverage is required to maintain the situation awareness of the operator at all times, while reducing the search time. The operator also wants a high-resolution capability to be able to identify detected objects. Those requirements are incompatible when using a single camera with conventional optical systems, because a wide field of view generally means a lower resolution, which is detrimental to the task of identifying. Also, as such missions may last several hours, with a high degree of concentration on the operator's part, the user-interface must be optimized to avoid unnecessary fatigue. The Infrared Eye concept was developed to answer those special requirements. Following a first laboratory prototype, a second one was designed to experiment the concept from an airborne platform, in realistic scenarios.

The IR Eye concept is based on the human eye and uses simultaneously two fields of view to optimize area coverage and detection capability. It integrates two cameras: the first camera, with a wide field of view (WFOV) of 40°, is used for search and detection while the second one has a narrower field of view (NFOV) of 10°, giving the higher resolution required for identification; this narrower field is mobile within the wide field and slaved to the operator's line of sight by means of an eye-tracking system. The images from both cameras are fused and shown simultaneously on a high resolution CRT display unit, interfaced with the eye-tracking unit in order to optimize the human-machine interface.

The IR Eye system was flight tested using the Advanced System Research Aircraft (Bell 412 helicopter) from the Flight Research Laboratory of the National Research Council of Canada.

This memorandum describes the prototype and its design approach, presents some results of the flight tests, indicates the strengths and deficiencies of the system, and suggests future improvements for an advanced system. Following the flight test, corrective actions were taken to solve some technical and user interface deficiencies. Those corrections are also described.

Although the WFOV detection capability for point target was limited, as expected, the flight has demonstrated the absolute necessity and usefulness of the WFOV image for the situation awareness and orientation of the operator with respect to the observed scene from the helicopter. The NFOV image alone was insufficient to make a correlation with the visually observed scene and to quickly find back the target when it went off the NFOV image part.

Ricard B., Chevrette P., Pichette M.. 2002. Infrared Eye: prototype 2. TM 2002-171 DRDC Valcartier.

Sommaire

L'objectif de l'Oeil Infrarouge (IR) est d'améliorer la capacité d'opération la nuit ainsi que dans des conditions atmosphériques adverses lors des missions de surveillance générale et de recherche et sauvetage, non seulement par l'utilisation de caméras à infrarouge (appareil d'imagerie thermique), mais aussi en intégrant un système mieux adapté aux besoins des missions et de l'utilisateur. Pour mener efficacement de telles missions, particulièrement d'une plate-forme aéroportée, il est nécessaire de couvrir une grande surface, tant pour maintenir la conscience de la situation de l'opérateur en tout temps que pour diminuer le temps de recherche. L'opérateur requiert également suffisamment de résolution pour pouvoir identifier les objets détectés. Ces exigences sont incompatibles lorsqu'on utilise une seule caméra avec un système optique conventionnel, parce qu'un champ visuel large implique une moins bonne résolution, ce qui est néfaste à l'identification. De plus, comme ces missions durent plusieurs heures et exigent une grande concentration de la part de l'opérateur, l'interface usager doit être optimale afin de réduire la fatigue. Le concept de l'Oeil IR a été mis au point pour répondre à ces exigences particulières. Après un premier prototype de laboratoire, un second a été conçu pour expérimenter le concept à partir d'une plate-forme aéroportée, dans des scénarios réalistes.

Le concept de l'Oeil IR est basé sur l'œil humain et utilise simultanément deux champs visuels pour optimiser à la fois la surface couverte et la capacité de détection. Deux caméras sont intégrées : la première, avec un grand champ visuel (WFOV) de 40°, est utilisée pour la recherche et la détection, tandis que la seconde, avec son champ plus étroit de 10°, possède la haute résolution nécessaire à l'identification. Ce champ étroit est mobile à l'intérieur de grand champ, et asservi à la direction de regard de l'opérateur sur l'affichage par l'intermédiaire d'un oculomètre. Les images des deux caméras sont fusionnées et affichées simultanément sur un écran à haute résolution, auquel est couplé un oculomètre afin d'optimiser l'interface usager.

L'Oeil IR a été testé en vol sur l'hélicoptère Bell 412 de recherche sur les systèmes évolués du Laboratoire de recherche en vol du Conseil national de recherches Canada.

Ce mémorandum décrit le prototype et la démarche suivie lors de sa conception, présente quelques résultats du test en vol, indique les forces et les faiblesses du système et suggère les améliorations à apporter pour un système plus évolué. À la suite des tests, des mesures ont été prises en vue de corriger certains problèmes techniques et d'interface usager. Ces correctifs sont discutés.

Même si comme prévu, la capacité de détection de sources ponctuelles était limitée dans le WFOV, le vol a démontré la nécessité et l'utilité de l'image WFOV pour préserver la conscience de la situation de l'opérateur et son orientation par rapport à la scène telle que vue de l'hélicoptère. L'image NFOV à elle seule ne permettait pas de faire une corrélation avec la scène observée visuellement et de retrouver rapidement la cible lorsqu'elle sortait de ce champ visuel.

Ricard B., Chevrette P., Pichette M.. 2002. Infrared Eye: prototype 2. TR 2002-171 RDDC Valcartier.

Table of contents

Abstract i

Résumé i

Executive summary iii

Sommaire iv

Table of contents v

List of figures vii

List of tables vii

1. Introduction 1

2. Description of the Infrared Eye concept 1

3. Opto-mechanical NFOV pointer 4
   - 3.1 The eye in the control loop 4
   - 3.2 Description of mechanical mounting and driving 5
   - 3.3 Pointing calibration procedure 6

4. Control software and user interface 7
   - 4.1 Crew station interface 7
   - 4.2 Image acquisition interface 8

5. Flight test 8
   - 5.1 Aircraft installation 8
   - 5.2 Airborne results, first flight 9

6. Corrective actions taken following the flight test 14

7. Future improvements 16
   - 7.1 VIZIR 16
   - 7.2 Step-stare 17

7.3 Pixelless QWIP/LED 18

8. Conclusion 19

9. References 20

Distribution list 22

List of figures

Figure 1 - IR Eye optical head with WFOV and NFOV IR cameras and Risley prisms 2

Figure 2 - Eye-tracking systems............3

Figure 3 - Section view of the opto-mechanical pointer and prism holder............5

Figure 4 - Crew Station control tool bar............8

Figure 5 - Installation on Bell 412 from FRL, NRCC............8

Figure 6 - Image of a parking lot as captured with the IR Eye system............11

Figure 7 - View of a freeway exchanger as captured with the IR Eye system............12

Figure 8 - Cows in a field, as captured by the IR Eye system............13

Figure 9 - IR Eye control interface kneepad............15

List of tables

Table 1 - Narrow Field of View displacement strategy............4

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1. Introduction

The purpose of the Infrared Eye is to improve night and adverse weather capabilities during general surveillance and search-and-rescue (SAR) missions, not only by using infrared (IR) or thermal imagers, but by providing a system which is better adapted to mission and user's requirements. To conduct such missions efficiently, particularly in airborne scenarios, a wide area coverage is required to maintain the situation awareness of the operator at all times, while reducing the search time. However, the operator also wants a high-resolution capability to be able to identify objects detected. Those requirements are incompatible when using a single camera with conventional optical systems, because a wide field of view generally means a lower resolution, which is detrimental to the task of identifying. Also, as such missions may last several hours, with a high degree of concentration on the operator's part, the user-interface must be optimized to avoid unnecessary fatigue. The Infrared Eye concept was developed to answer those special requirements. A first laboratory prototype was developed to explore the feasibility of the basic concept [1]. Based on the lessons learned during the first development, a second prototype was designed, to solve the deficiencies of the first one and to experiment the concept from an airborne platform, in realistic scenarios. This memorandum describes the latest system, shows some results from the first flight tests and explores future developments.

This work was carried out at DRDC Valcartier between April 2000 and April 2002 under Thrust 3D (Airborne Search & Localization Systems), project 13DA (Day and Night Search Missions), and under the New Search & Rescue Initiative Funds (NIFID: 98037) program from the National Search & Rescue Secretariat (NSS).

2. Description of the Infrared Eye concept

The IR Eye is a new concept of search and rescue (SAR) and surveillance system. It is based on the human eye, with simultaneous wide (WFOV) and narrow (NFOV) fields of view, individually enhanced for sensitivity and resolution, respectively, for their specific task of detection and recognition/identification [2,3]. The WFOV spans 40° horizontally, while the NFOV covers 10° and is mobile within the WFOV. A special display concept, better adapted to the human vision, uses a very-high-resolution CRT display for the fusion of the images from both the WFOV and NFOV cameras. An eye-tracking system determines the gaze direction of the operator on the display to steer the field of view of the NFOV camera and adequately overlay its high-resolution image on the WFOV image on the high-resolution display monitor, aligned with the operator's central vision.

The resolution was prioritized over the waveband for the selection of the cameras, in order to optimize the detection capability in the WFOV. The IR camera with the highest resolution that could be found on the market was a Mitsubishi IR-M700, with a PtSi focal plane array (FPA) of 800 x 512 pixels. The camera operates in the 3-5 μm band. Ideally, the 8-12 μm band would be preferable for the envisaged applications, but no high-resolution FPA was commercially available at the time. Two IR M700 cameras are used in the system for the WFOV and the NFOV, respectively (Figure 1).

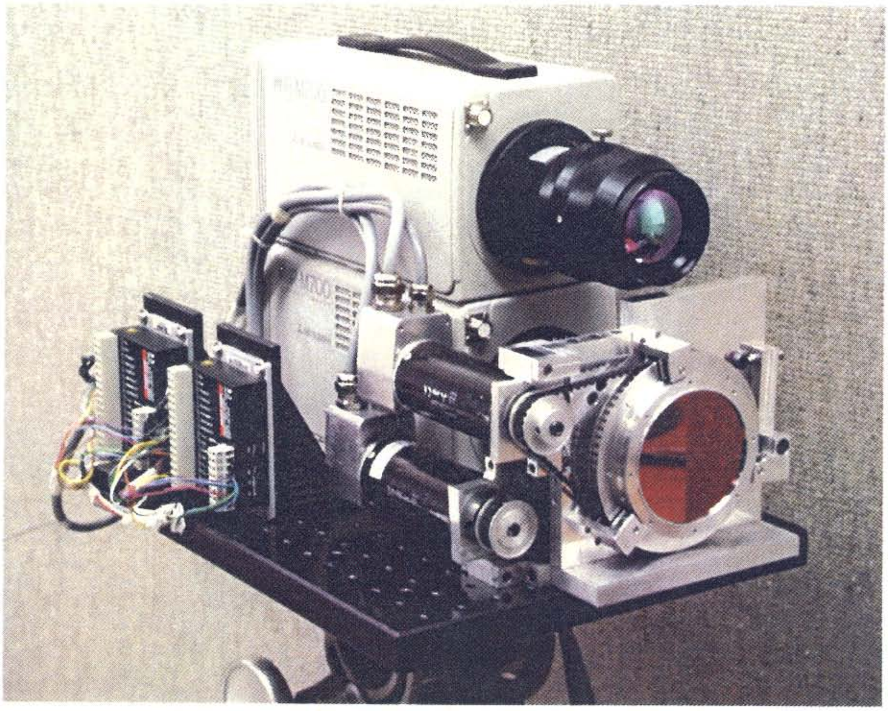

Figure 1 - IR Eye optical head with WFOV and NFOV IR cameras and Risley prisms

The field-of-view of the NFOV camera is steered by means of an opto-mechanical pointing system made of two 80-mm diameter achromatic Risley prisms, silicon/germanium doublets specifically designed for the application by the National Optics Institute, Quebec [4]. NOI also designed the NFOV 58-mm, *f*/1.3 objective lens with a ± 10% zoom capability, to allow for the adjustment of the 4:1 ratio between the two FOVs. The prisms are mounted coaxially with the camera objective, which avoids the folded path and image rotation introduced by a two-axis moving mirror (as in the first prototype), thus making the system more compact and less sensitive to vibrations, an important criterion for airborne applications.

The 4:1 ratio between the two FOVs imposes constraints on the display system since the NFOV image must be properly positioned and overlaid with scale matching on the WFOV image. Since the NFOV image is 800 x 512 pixels and represents ¼ of the horizontal WFOV, the display must be capable of 3200 x 2048 pixels. No such high-resolution display could be found. However, the DEX2105L, available from Clinton Electronics (Orwin), can display 2560 x 2048 pixels. It is a bulky CRT specially designed for airborne operation. By limiting the frame grabbing from the IR M700 cameras to 640 x 512 pixels, this display was suitable for our prototype.

For positioning the NFOV, three eye-tracking systems were tested (Figure 2). The first two are models 501 and 504 from Applied Science Laboratories. The third system, our final choice, is model RK-726PCI from Iscan inc.

Both ASL models use the bright-pupil/corneal reflection principle and can be combined with a magnetic head-tracking system. Model 501 is a head-mounted system, while model 504 is a desk-mounted pan-tilt camera, thus eliminating all head-mounted apparatus. Those systems are good for psychometric experiments in the laboratory, but the magnetic head-tracker to be used in conjunction with them is unsuitable for operation in aircraft environment. Model 504 accepts head movements within a cubic foot, without the head-tracking system, but unfortunately, the tracking speed of the pan-tilt device is insufficient, and often times the system looses track when the head moves too fast, even within the allowed cubic foot.

The Iscan system met our expectations with an optical head-tracking principle and a dark-pupil/corneal reflection. The head-tracker consists of 6 light-emitting diodes (LED), mounted on the frame of the display monitor, and a small filtered camera on the head-mounted device (a cap), to view the LEDs. The only draw-back so far is the lack of some library functions to integrate the system to the IR Eye control software. Iscan is currently developing this library. The IR Eye NFOV can be steered either with a mouse click at the desired position on the WFOV image, or using the eye-tracking system.

The next section describes in more details the opto-mechanical pointer driving the Risley prisms, which is really the heart of the IR Eye.

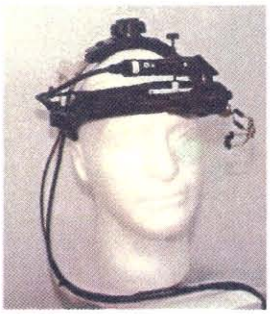		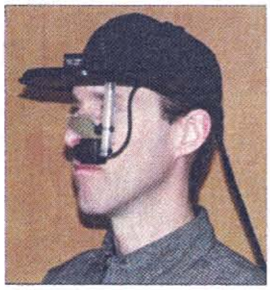
a) ASL model 501.	b) ASL model 504, desk mounted.	c) Iscan model RK-726.

Figure 2 - Eye-tracking systems

3. Opto-mechanical NFOV pointer

3.1 The eye in the control loop

To understand the challenge designing the high-resolution NFOV steering mechanisms, we have to understand how the operator's gaze direction (central vision) is used to move the high-resolution area of the image (NFOV) within the WFOV. The human eye is an extremely complex sensor but fortunately, to build the steering mechanism, we only need to consider how the eye moves to perceive objects and its ability to resolve moving scenes. The human eye angular rate of turn is more than twice faster than any mechanical system we could build to steer the camera NFOV. However knowing that the brain takes up to 130 msec [5,6,7,8] to resolve the image when the ocular globe comes to a stop, we can use this time to stabilize the prisms to their final positions and grab the image.

As mentioned above, an eye-tracking device is used to find where the operator gazes on the monitor. The computer analyzes the eye motions and moves the NFOV accordingly. However some filtering must be done on the data from the eye-tracking device to remove the eye saccadic motion This is a high-speed random motion of the ocular globe to extract the high-resolution details of a scene and to compensate instability in the neuromuscular system of the eyes [9]. The saccadic motion is performed on a relatively small portion of the foveal (central and high-resolution) region of the eye but at a speed that the mechanical system cannot withstand. To minimize the motion of the NFOV, we have conducted tests on the system to determine the largest "saccadic motion zone" tolerable without seeing the borders of the NFOV zone. Our experimentation gave a "no-motion radius" of 3° around the center of the NFOV, that is, if the eye moves within this zone, the NFOV position remains stable. However, we still experience sporadic motion of the NFOV when the eye pokes around outside this zone. We control this behavior by adding a second zone between 3° and 5° radius, in which we move the NFOV halfway toward the eye gaze point whenever it falls into that zone (Table 1).

Table 1 - Narrow Field of View displacement strategy

Eye displacement from the center of the NFOV	Displacement of the NFOV
0° to 3°	No move
3° to 5°	0.5 x the eye displacement
Greater than 5°	Reposition the NFOV centered on the eye gaze point

With this strategy, we achieve a comfortable motion of the high-resolution NFOV without undue mechanical constraints. The following section presents the different mechanical concepts we tried for steering the NFOV, based on the above precepts.

3.2 Description of mechanical mounting and driving

Numerous concepts have been studied to steer the NFOV around in the WFOV. Two main approaches have been retained: gimbaled mirrors and Risley prisms. With the first beam steering technique, the NFOV is acquired through a gimbaled mirror and a de-rotator prism (first prototype of the IR Eye). The prism is rotated in the direction opposite to the elevation axis to compensate for the image rotation around the optical axis. The challenge in this system is more in the optical alignment of the components than in the concept itself, particularly the de-rotator prism. With a system in the visible range, we could use a laser to center the prism on the optical axis but in the 3-5μm, we had to use an IR point-source, seen through all the optical components and use the resulting image from the camera to adjust the prism holding fixtures. We had good result in the laboratory and in controlled test environment [3]. The weak point of this prototype is the need for numerous adjustment points to control the position and the orientation of the de-rotator prism which is very sensitive to vibrations. It is also voluminous and heavy.

The initial goal of the current phase of the project (second prototype) was to build a ruggedized airborne prototype capable of withstanding harsh vibration and climatic conditions. To achieve this goal, we designed a new steering mechanism with a minimum number of parts and adjustment points. As mentioned before, the pointing system is built around two counter-rotating achromatic prisms, known as Risley prisms. Risley prisms consist of two identical round wedges (in fact, each wedge is a Ge and Si doublet) mounted on independent rotation mechanisms. Each prism deflects the image of the NFOV by a fix angular vector: in our case by 10.5°. By rotating each prism to a specific angle, it is possible to reach any point in a ±21° space. An advantage of Risley prisms is that they offer excellent mechanical stability, contrary to the mirror system, do not induce image rotation, and any constant angular error due to mechanical misalignment or imperfections can be compensated for at the calibration phase of the system (see 3.3). The rotation mechanism is composed of the prism holder that contains the Si-Ge doublet, 3 pairs of delrin rollers, gears, a 120W brushless

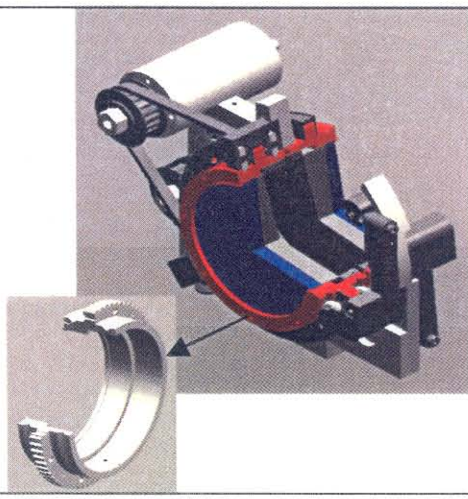

Figure 3 - Section view of the opto-mechanical pointer and prism holder

motor and a 10,000 pulses/revolution encoder. One of the design challenges was to build a system that could stay accurate and survive rotational acceleration up to 72,000°/s^2. It became obvious that the mechanical components should withstand huge accelerations and significant wearing without getting misaligned. The prism holder is supported by the 3 pairs of small delrin rollers mounted on ball bearings on each side of the driving gear. Two roller pairs are fixed to support the pulling force of the driving belt and the third one (at the opposite side of the motor) is spring loaded to control the pressure of the rollers on the holder. The prism holder is correctly aligned by two V grooves in which the rollers lean. Wearing could change the diameter of the rollers and could cause an eccentric motion of the holder without degradation of the pointing precision. The current prototype has been used for more than a year without noticing significant degradation of the pointing accuracy even if we have observed wearing flats on the delrin rollers. The mechanics is designed to be self-aligning (Figure 3).

3.3 Pointing calibration procedure

Although mathematical modeling could describe perfectly the deviation of the Risley prisms, a lack of precise indexing between the components of the doublets and of mechanical bore-sighting accuracy between the two cameras and the optical axis of the pointing system led us to develop a simple and effective calibration procedure and software. The calibration software produces a lookup table of the position of the prisms corresponding to the deviation angle measured from the center of displacement of the NFOV in the WFOV.

The Risley prisms can perform two basic deviation patterns by symmetric motions of the prisms. By turning both prisms in the same direction (coordinated rotation), the deviation pattern of the NFOV in the WFOV will describe concentric circles around a center of alignment corresponding to the optical axis of the NFOV camera . Symmetric counter rotary motion of the prisms gives linear motion of the NFOV through the center of alignment. Using these two basic motions, we can direct the center of the NFOV toward any point in the WFOV space. Converting the Cartesian pointing coordinate in the WFOV to polar coordinates gives us the radial distance of a point from the NFOV center of alignment, and the rotation angle from an arbitrary origin (angle of rotation on a concentric circle). The calibration process, in brief, consists in finding the correspondence between points on a line extending from the center of alignment of the NFOV in the WFOV image to the WFOV border, and the angular positions of the steering prisms. The calibration process also removes the need for precise bore-sighting between the NFOV and the WFOV cameras.

To calibrate the system, the camera head is installed sideway on a pan & tilt platform. The tilt axis is used to make the panning plane of the platform parallel to the horizontal axis of the camera. The tilt is adjusted in such a way that a distant point-source target (farther than 100m) appears to travel on a horizontal line when panning the camera head. The second step is to find the prism index positions which gives the minimum NFOV deflection, that is the point where, for a coordinated rotation of the prisms, the translation movement of the image is minimum. In fact, with the prisms at those angular positions, we should not see any movement of the image. But due to the lack of positioning index on the doublet elements and the mechanical tolerances in the prism design, we observe a motion radius of 3 pixels in the NFOV with the current system, representing a pointing error of 1.6 mrad in the worst case. Now, knowing the no-deflection prism positions, we move the camera head for the point source target to appear at the NFOV image center and mark the corresponding point in the WFOV, which corresponds to the center of alignment of the NFOV and its center of rotation for all displacements with the prisms. At this point, the images of the cameras should be more or less bore-sighted. The third step is to turn the camera head by half a degree increments, to mark the target image in the WFOV and rotating the prisms to bring the target image in the center of the NFOV. Recording those points build the calibration table of the system. The points are all on a horizontal line, which corresponds to the 0° axis of the coordinated-rotation angle.

To move the NFOV to a point in the WFOV, we calculate the polar coordinate of this point with respect to the NFOV center of alignment, we find the radius of the point in the calibration table (linear interpolation is used) and we add to the corresponding prisms position, the coordinated rotation angle to reach the point in the WFOV.

4. Control software and user interface

4.1 Crew station interface

In September 2001, we flew with version 4.0 of the crew-station human-machine interface software (HMI). Except for problems found in the acquisition thread, the main improvement from the previous versions was a simplified control interface. From previous ground-based experiments, we determined which controls were essential to the mission progress as opposed to system management and diagnostics. System management and diagnostics have been moved to applications specific to these tasks. The control functions are found in three groups (Figure 4).

The first group takes care of the image controls. The cameras provide us with 10-bit images from which we select a range to be fitted to the 256 gray levels of the high-resolution monitor. This range is controlled by a motion of the mouse on the screen and three on-screen sliders. An up and down motion of the mouse increase or decrease the span (or the number of gray level from the camera). A leftward or rightward motion of the mouse change the offset of the image (or the smallest gray level presented). On-screen sliders can also be used to select and visualize the lowest and the highest gray level presented. An on-screen button allows to switch the control action from the NFOV to the WFOV. The second group contains the recording functions. The first recording functions subgroup controls still-image capture (freeze image and save to disk). The second recording functions subgroup controls the live image recording and playback. As on a VCR, we find the Record, Play and Stop buttons. The Fast forward and Rewind buttons in addition to skip in time could jump to recorded events as typed memo, target detection and tagged images. The images and data are recorded digitally at 7 frames per second for mission archiving. Finally, we grouped all together the displaying of system and mission status. In a box, we display the mission current time, the recorder timing and active function. In following version of the system, we will also display the aircraft altitude, heading and position in this zone.

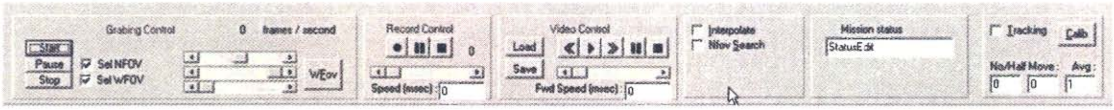

Figure 4 - Crew Station control tool bar

4.2 Image acquisition interface

The image acquisition interface controls four independent threads that perform the following functions, respectively: 1) to grab images from the frame-grabber cards; 2) to perform eye-tracking and direction of regard management; 3) to control the NFOV image steering mechanics; 4) to enhance point-target detection in view of helping the SAR operator in finding small and faint target (in development).

5. Flight test

5.1 Aircraft installation

Figure 5 - Installation on Bell 412 from FRL, NRCC

The IR Eye was flight-tested in cooperation with the Flight Research Laboratory from the National Research Council of Canada's Institute for Aerospace Research, on their Advanced Systems Research Aircraft, a Bell 412 helicopter. This helicopter is similar to the Griffon, owned by the Canadian Forces, a candidate aircraft to eventually fly the IR Eye on search-and-rescue or surveillance missions. At this stage of development, the IR Eye packaging was not quite suitable for standard flight missions and required a very flexible certification and operation methodology, which only FRL could supply.

An aluminum cover with tilted germanium windows was installed over the camera head to protect it against dust and weather. A small video camera operating in the visible band was affixed to the cover. The camera head was mounted on a Tyler Middle Mount II, a man operated airborne stabilization platform used in the cinema industry. The Tyler Mount was strapped to the helicopter floor behind the pilot seat and the operator could sit in the Tyler mount seat with feet on a foot support overhanging the open cargo side door, on the port side of the aircraft, to point the camera head in the proper direction (Figure 5).

A special floorboard, made by FRL, was bolted to the floor on the starboard side, to serve as a support for the electronics rack. The rack itself, of soldered aluminum struts, was based on an approved design for airworthiness acceptance, and held the heavy (85 lbs) high-resolution display monitor, the industrial computer, power supplies for the cameras and the prism drive motors, and two video recorders for a backup recording of the flight test (one recorder was used for the WFOV IR cameras and the other could be switched between the NFOV and the visible cameras). The keyboard had an included joystick-type mouse and was mounted in a drawer so that it could be moved out of the way during take-offs and landings.

The aircraft was equipped with an inverter that could supply 110V/60Hz, 10A, from the 28VDC, which was amply sufficient power for our system. The inverter is also a standard equipment on the CF Griffon.

5.2 Airborne results, first flight

The first flight was scheduled for September 12, 2001, with the participation of a SARtech (search-and-rescue technicians) team from Trenton, Ontario, CA. The plan was to fly from Ottawa to Trenton and to simulate SAR scenarios on Lake Ontario, using small boats and including a man in water, with the cooperation from the SARtechs. Unfortunately, because of the September 11 events, we were grounded until the 13th, noon time, and the participation of the SAR team was canceled. Our flight was limited to some specific training areas near Ottawa. The objectives of that first flight were to determine the operability of the system in a real helicopter environment and the efficiency of the stabilization with the Tyler Mount, to evaluate the effect of the low-frame-rate display (about 7 fr/s) with moving scenes, and finally to do preliminary performance tests with a someone on the ground in a semi-forested area.

Figures 6 to 8 show images as presented on the high-resolution display. Those images are composed by blowing the WFOV image (640 x 512 pixels) by a factor of 4 x 4 to fill the 2560 x 2048 pixels of the display screen, and then inserting the NFOV image in the proper position and in its normal dimensions (640 x 512), to preserve the relative angular coverage of each FOV. The difference in resolution capability between the two FOVs is obvious. Defects are also apparent, showing errors in magnification and sometimes in position. On some images, interlace problems are apparent as either an inversion of frame fields or a field separation caused by rapid movements of the scene between the field grabbing.

The following preliminary observations were made after the flight test:

- The stabilization with the Tyler mount is adequate, but its use is strenuous on the operator because of wind effect. Its open-door operating requirement is incompatible with the real all-year-round search-and-rescue operational environment.

- The major drawback was the splitting between the interlaced fields composing the WFOV images when the scene is moving and while digital sequences are recorded (which slows the processor). This problem does not seem to occur in the NFOV. This is a software problem caused by the interlace format of the digital video output from the cameras and by a heavy workload on the processor. Also, sometimes the order of the fields seems to be inverted, which is also a software problem caused by the incompatibility of the video output from the cameras with the acquisition cards.

- The low frame-rate (7 fr/s) seems tolerable to the operator, as the steps between images is a small portion of the FOV, as long as a full frame is grabbed with two consecutive fields.

- The in-flight adjustment of contrast and brightness for both cameras (crew station interface) needs improvement. Using an airborne intended system on ground led to misevaluating parameters specific to airborne platforms like vibrations, strong and changing translational and rotational accelerations (in 3D), fast changing illumination conditions and restricted work space. We found the screen-based user-interface and the on-screen buttons difficult to use and disturbing. At design time, we took a special care in using the simplest and stable pointing device (Hula Point joystick on a keyboard, model 5000 from Stealth Computer) and in finding the most effective way to use it, but the flight conditions were worst than what we were expecting to deal with. This kind of pointing device and on-screen user interface is not really effective and disturbs the operator from its main task namely: searching for targets, rather than following the Windows mouse pointer! In fact, with this type of user interface, three operations must be performed: finding the pointer on the screen, finding the on-screen button to click and moving the pointer to the on-screen button. It seems simple, but in flight condition, all the operator's attention is required to coordinate those operations on a high-resolution display where cursor and button icons become very small, which makes the operator loose track of the mission progress.

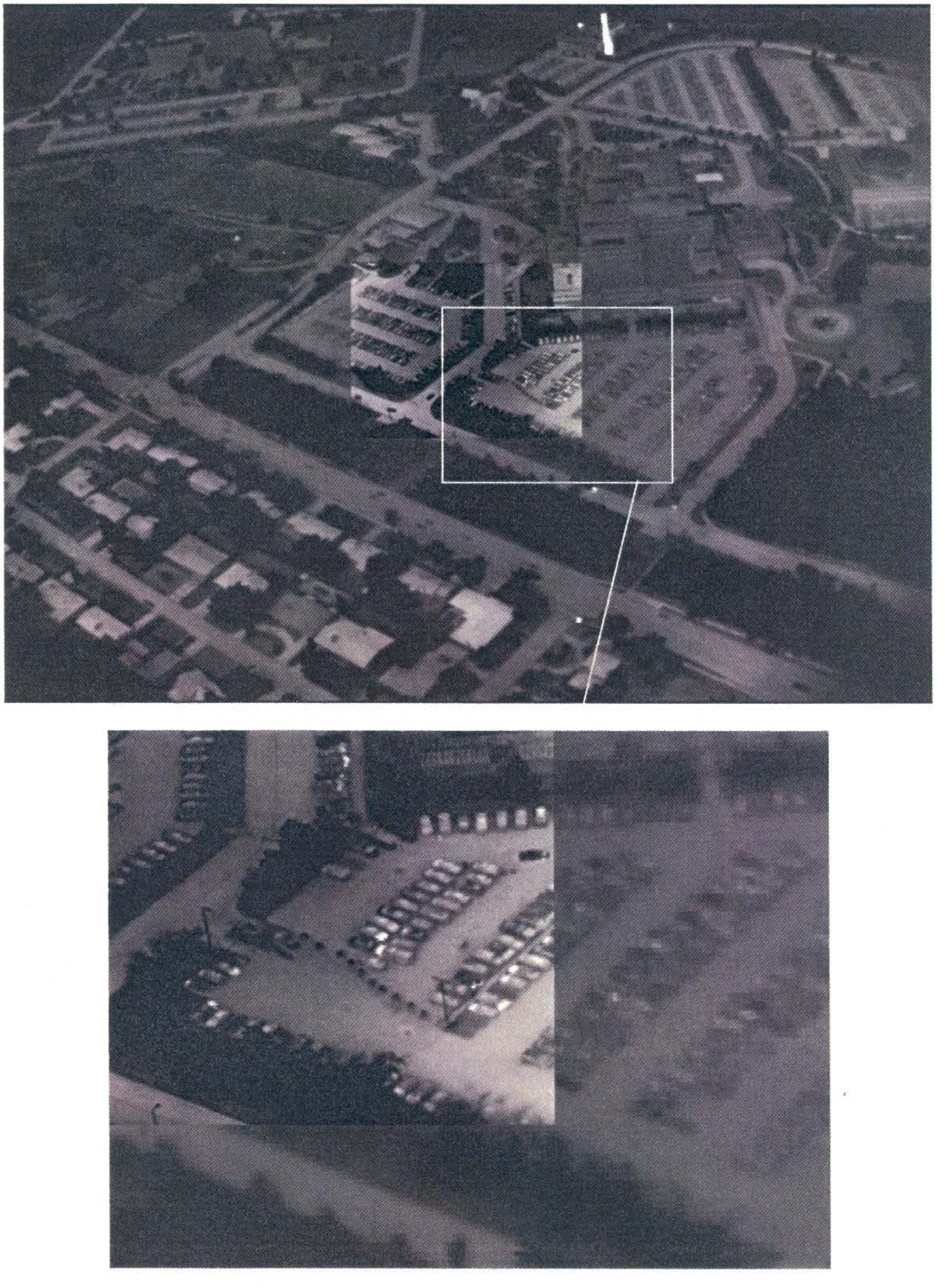

Figure 6 - Image of a parking lot as captured with the IR Eye system

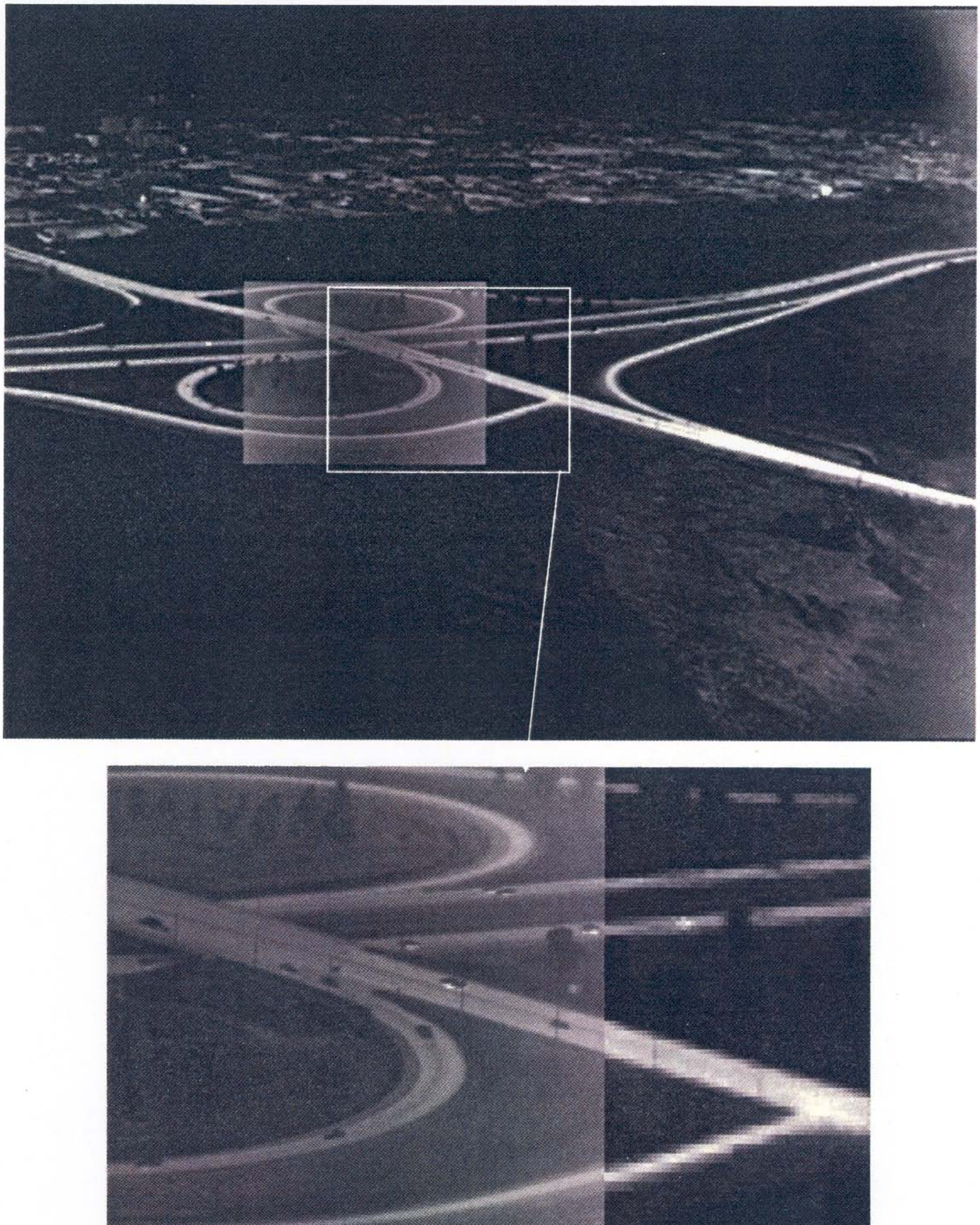

Figure 7 - View of a freeway exchanger as captured with the IR Eye system

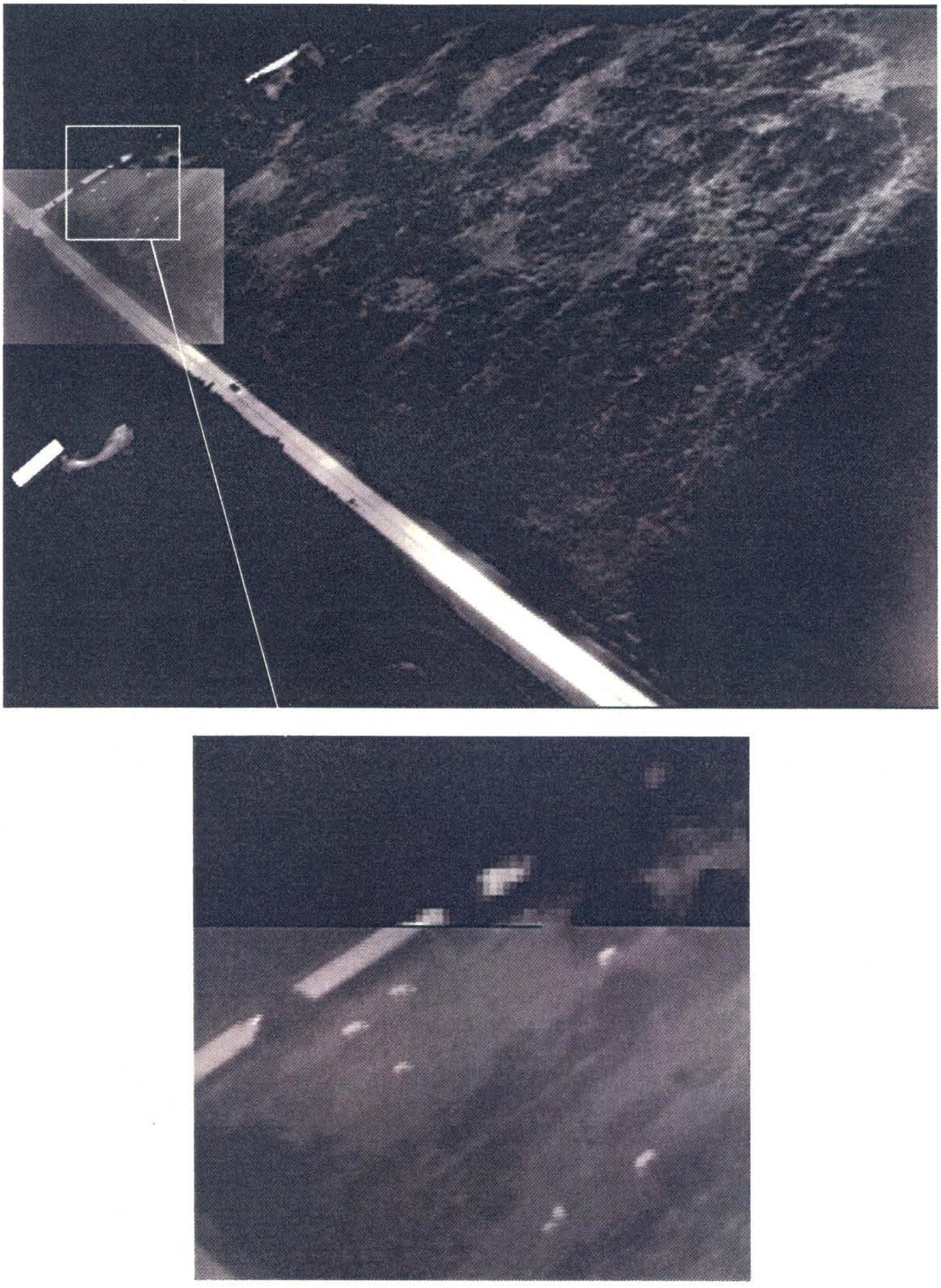

Figure 8 - Cows in a field, as captured by the IR Eye system

- The digital sequence recording software did not work properly. Only still, composed digital images could be recorded (as viewed on the high-resolution display screen).
- The 4-in LCD display, mounted on the Tyler mount seat to help the operator in pointing the camera head, was inadequate in terms of contrast and viewing angle and its mounting position was not ideal for the operator's comfort.
- As expected, the WFOV did not perform very well in detection mainly for three reasons:

    1. at constant *f*/number a loss of aperture occurs when optically increasing the FOV on a sensor by changing the focal length of the objective. In our case a 4:1 ratio between the WFOV and the NFOV results in a 16 time reduction of the aperture area, with an equivalent loss in detection capability;
    2. at lower ambient temperatures, the 3-5 µm band is not the best choice for low-contrast imaging because of the lower available signal in that band;
    3. the contrast between the man and the background was further reduced by the sun heating of the background.

- However, the flight has demonstrated the absolute necessity and usefulness of the WFOV image for the situation awareness and orientation of the operator with respect to the observed scene from the helicopter. The NFOV image alone was insufficient to make a correlation with the observed scene and to quickly find back the target when it went off the NFOV image part.

All problems and deficiencies were noted of in view of improving the system for other flight tests to follow.

6. Corrective actions taken following the flight test

After the first flight, the equipment was brought back to the laboratory and the effort was directed toward correcting the noted deficiencies.

- The most important problem was the apparent splitting between the interlaced fields composing the images, particularly apparent in the WFOV. This problem became apparent when there was a scene motion and was further enhanced because the fields did not seem to be grabbed consecutively; it was also accompanied sometimes by an inversion between the odd and even fields. As previously mentioned, this problem was caused by a frame-grabber card not designed for interlaced digital video input (Road Runner from BitFlow) Before the flight test, an attempt was made to correct the card deficiency by software, grabbing fields separately and then composing the image into the graphic memory

To solve this problem, tests were performed with a Meteor card from Matrox, which is designed to accept interlaced fields. The tests were successful and we are in the process of adapting the control software to integrate Matrox cards in replacement of the BitFlow cards. The computer was upgraded to a dual 1-GHz processor board, in an attempt to increase the frame-grabbing and processing speed.

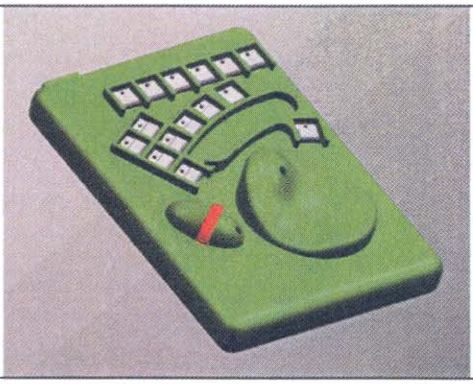

Figure 9 - IR Eye control interface kneepad

- To improve the user interface, we studied some options like "mechanical" buttons and sliders on the screen frame, or using the eye-tracking device with on-screen labels. The first solution is frequently found in moving platform like airplanes or tanks. In our case, this solution was not ergonomic as the operator is continuously using the interface and his arms will never rest on something, rapidly leading to operator fatigue. The eye-tracking device could be a nice input device for the operator console but would be too complex to use and could be unreliable. The solution adopted is a knee-pad of function keys and a thumb wheel. The keys are positioned to be used without looking at the knee-pad to find them. This type of user interface allows the operator's hands and arms to rest in an ergonomic position and to use the system with convenience. The interface will be completed before our next flight with the system (Figure 9).

- The corrections to software for the digital recording of sequences are nearly completed.

- Some tests were carried with a variety of head-mounted micro-displays, purchased within another DRDC Valcartier project, in view of using those as a viewing aid for the operator sitting in the Tyler Mount and pointing the cameras to the target. The micro-displays will be made available for our next flights.

- A low-cost in-house stabilization mount has been designed and components are being tested and manufactured at our machine shop. This mount will be compatible with the support used on the Bell 412 for the Wescam ball and will allow to fly with the cameras mounted outside the helicopter, which should be a better adaptation for the considered applications. The IR Eye requires a stabilization precision significantly lower than what the Wescam units can provide because of its relatively large fields of view and the tolerance of a human operator to low-frequency movements of the platform.

- A laboratory characterization of the complete system was made. This evaluation includes the exact spectral response of the camera, the spectral transmission of the prisms, the resolution (MTF), distortions and the NETD figures with and without the prisms, and the positioning accuracy of the opto-mechanical system. Other electronic characteristics such as the slew-rate and the optimum frame-rate will also be measured, when software and hardware configurations will be finalized. This will help in understanding and predicting the performance of the system in future tests and in determining technical solutions to the deficiencies for future systems.

- The next ground-based and flight tests will concentrate on the system efficiency in SAR missions, and try to determine detection and recognition ranges for a variety of targets and scenarios, in various types of backgrounds and weather conditions.

7. Future improvements

As the development of the IR Eye prototype is being finalized to make it an airworthy demonstration system, future evolutions are envisaged to refine its efficiency and usefulness.

7.1 VIZIR

The VIZIR project, also supported by NSS, consists in adding an active, range-gated, near-infrared (NIR) camera in the NFOV to enhance the effectiveness of the system and take advantage of the NIR technology in using the reflective characteristics of the target. For instance, thermal IR does not allow to read letterings on a ship because most paints have an emissivity close to one in the thermal IR, irrespective of their visual color, which reduces to nothing the emissive contrast in the thermal IR bands. In the NIR band, the difference in reflectivity between different color paints is about the same as in the visible band and produces a readable contrast The use of an active system (with an illuminator) also adds the possibility of detection of optical systems, including the eyes of a person, through the cat-eye effect, or a retro-reflection of the illuminating light from the focal plane of the optical system. Finally, the range-gating capability allows to penetrate to some extent (depending on the power of the illuminator) adverse weather conditions such as fog, rain or snow, by eliminating the backscattering from the optical path between the camera and the target. The range to the target is obtained as a by-product. DRDC Valcartier has developed an expertise in active, range-gated cameras [10]. The VIZIR system will let the operator select either the IR or the active image for the NFOV portion of the displayed image, and to zoom on the target for a better identification. The possibility of a fusion of the IR and active images is also considered.

A laboratory prototype is being developed at DRDC Valcartier and will operate in the 8-12 μm IR band for both WFOV and NFOV. An active NFOV with a laser illuminator at 0.855 μm are added. The laser illuminator diode array (28 W at 15.75 kHz pulse rate) has been designed and manufactured by NOI. The Risley-prism approach is taken for all moving FOVs. The VIZIR projects will benefit from the expertise developed within the IR Eye project for the control software, as well as in the design and fabrication of opto-mechanical pointers.

7.2 Step-stare

The original idea behind the IR Eye concept was to develop a system which, similarly to the human eye, could show as good, if not better, detection capability in the WFOV than in the NFOV. The human eye peripheral vision is 5 orders of magnitude better in sensitivity than in its central vision, which makes our peripheral vision our detection sensor, drawing our attention so that we bring our central vision to the detection area to identify the cause of anomaly. Of course, our peripheral vision is quite complex, involving sophisticated processing through a neural network onto the retina, before a signal is sent to the brain. For SAR as well as general surveillance applications, this is the kind of sensor that is required, to cover large areas with a low risk of missing a target. Unfortunately, conventional optics and sensor technology do not allow yet to combine high point-source (smaller than the pixel angular coverage) detection sensitivity and a large FOV. Our eyes use the same lens aperture for both our peripheral and central vision, which guarantees at least the same signal amplitude for a given point source. The increase in FOV is obtained by a larger sensor area. With conventional optics, since the sensor dimensions are limited, we increase the FOV by reducing the focal length of the lens. Since the f/number is fixed by the sensor cold-shield, a shorter focal length results in a smaller aperture, limiting the amount of energy captured for the same point source, therefore limiting also the signal amplitude and the detection capability.

In the absence of large area focal plane arrays, one solution is to build the WFOV as a mosaic of images taken with the NFOV optics. Our Risley prism approach allows us to do that elegantly, without moving the whole camera. For optimum operation speed, a snapshot (instead of rolling integration) camera is required to minimize the loss of frames between displacements of the FOV, but also to minimize image distortion due to motion of the scene within each frame when each line is integrated sequentially. The limiting factor would be the slew-rate of the prisms to properly position the NFOV, but since the desired positions are fixed and adjacent in space, the positioning sequence would be repetitive and could be made to minimize the relative prism displacement between positions, thus optimizing the grabbing speed for the overall mosaic WFOV. Each NFOV image composing the WFOV being a snapshot of relatively short integration time, the scene motion blur on each individual snapshot would be minimal; the scene displacement between snapshots could be compensated on the display by accounting for the displacement from navigational information and properly positioning the snapshots on the screen in a puzzle-like fashion.

The development of algorithms to accomplish such a motion compensation will be experimented using a simulator developed by LYRtech Inc. for psychometric experiments related to the IR Eye concept. Special algorithms will also be studied for pixel compression of the high-resolution WFOV image obtained by step-stare, while preserving the detection capability. The full resolution would be presented in an area around the operator central field of regard on the display, determined by means of the eye-tracker, while in the rest of the image, pixels could be fused into larger pixels on an intensity basis (instead of averaging) to preserve the detection capability. For example, within a group of pixels, the maximum intensity could be determined, and a larger pixel with that maximum intensity could be presented on the screen in lieu of the group of pixels, which should draw the attention of the operator. Eventually, if the overall acquisition frame-rate is sufficiently high, one of the camera could be eliminated, keeping the eye-tracking system to determine image areas with different compression and processing schemes.

7.3 Pixelless QWIP/LED

A second solution to preserve the point-source detection sensitivity in the WFOV is to fabricate a larger sensor in order to capture a wider FOV with the same lens and the same aperture as that of the NFOV. DRDC Valcartier is currently pursuing that approach in cooperation with the Institute for Microstructural Sciences (IMS) of the National Research Council of Canada. Dr. H.C. Liu from IMS has developed a new type of infrared sensor called a pixelless quantum-well-infrared-photodetector coupled with a light-emitting-diode layer (QWIP-LED) [11]. Basically, this sensor is a converter from thermal infrared wavelengths to near-infrared ($\approx$0.85 µm). The sensor is based on GaAs and QWIP technologies. The QWIP part is made of superposed layers of GaAs and AlGaAs materials. The thickness of the layers determines the detector waveband, which thus can be tuned over a fairly broad range of the thermal IR spectrum. A few more added layers constitute a LED through which must pass all photoelectrons generated by the capture of infrared photons in the QWIP part, to reach the biasing electrode. In the process, the photoelectrons are converted into NIR photons. The device is quite simple of fabrication and operation, requiring only two wires and low voltage for its biasing. Since the overall thickness is of the order of 2 microns, the lateral diffusion of photoelectron is small and it is not necessary to subdivide the sensing area into individual pixels, the excitation and photon conversion remaining local, hence the "pixelless" denomination. The resolution is then mainly determined by the size of the blur spot from the front optics. Another advantage of the simplicity of the device is that it can be made in large format. We are aiming at fabricating a 4 cm x 4 cm IR sensor, to cover a WFOV of 40° with the same lens focal length as we are currently using for the 10° NFOV. The light emitted from the LED side is imaged onto a CCD sensor, sensitive to the NIR wavelengths.

The main drawback is the difficulty in coupling out the NIR light from the LED because of the high index of refraction of the GaAs substrate material. It is planned to use a fiber-optic faceplate in close proximity to the LED surface to increase the external coupling efficiency.

The research is progressing well and it is hoped that eventually such a large area device will constitute the heart of the IR Eye, eliminating the need for two cameras. As in the step-stare case, special processing algorithms could be used to compress the imager data while preserving the detection capability in the wide field and the resolution in a smaller area centered on the operator's line of sight.

8. Conclusion

The feasibility of the IR Eye concept, with two fields of view operating simultaneously, by analogy with the human eye, has been first demonstrated with a laboratory prototype. A second prototype, using the latest IR focal plane array camera technology for a smaller and lighter system with a higher resolution, was built to test the concept in more realistic search-and-rescue and surveillance scenarios, from an airborne platform. The system was further improved in compactness and ruggedness by using Risley prisms instead of a gimbaled mirror and a de-rotator prism to steer the field of view of the NFOV camera within the field of the WFOV camera. A special doublet prism design was required to make the prisms achromatic within the IR waveband of the cameras. Similarly, a special opto-mechanical system was designed to hold and rotate the prisms with the accuracy required for the application. The system was integrated with general control software allowing all the necessary control functions for the camera adjustments, the reading of the eye-tracking system, the positioning of the prisms, the superpositioning of the two FOVs on the high-resolution display and the recording of composed images. Finally, the system was mounted on a helicopter and tested during a first flight in order to determine its airworthiness and user-interface deficiencies. Corrective actions were taken following the flight in view of improving particularly the user interface for controlling the cameras and for improving the overall frame-rate and display quality. Future flights will concentrate on measuring the efficiency improvements in SAR scenarios.

A number of areas have been identified for further research and development in order to extend the capability of the IR Eye and improve its sensitivity and performances. The addition of a range-gated active camera is already in progress and the integration of the complete system will begin soon. To increase the sensitivity and detection capability in the WFOV, two approaches are considered: the development of a large-area pixelless QWIP-LED sensor could lead to a single camera to perform the same tasks currently done with the dual-camera IR Eye system. However, since the development of such a sensor is still in a research phase, a step-stare approach could be an acceptable compromise, by building the WFOV out of a mosaic of NFOV image and appropriately tiling them together on the display to compensate scene motion. It is hoped that advances in technology (e.g. uncooled IR sensors) will allow the miniaturization of the system and its reduction in size and weight, thus making it more practical for integration to small airborne stabilization mounts. The IR Eye has many other application possibilities as a landbased and shipboard system, which have not been explored yet.

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The Infrared (IR) Eye was developed with support from the National Search-and-Rescue Secretariat (NSS), in view of improving the efficiency of airborne search-and-rescue operations. The IR Eye concept is based on the human eye and uses simultaneously two fields of view to optimize area coverage and detection capability. It integrates two cameras: the first, with a wide field of view of 40°, is used for search and detection while the second camera has a narrower field of view of 10°, giving the higher resolution required for identification; this narrower field is mobile within the wide field and slaved to the operator's line of sight by means of an eye-tracking system. The images from both cameras are fused and shown simultaneously on a high resolution CRT display unit, interfaced with the eye-tracking unit in order to optimize the man-machine interface. The IR Eye system was flight tested using the Advanced System Research Aircraft (Bell 412 helicopter) from the Flight Research Laboratory of the National Research Council of Canada. This report describes the prototype and its design approach, presents some results of the flight tests, indicates the strengths and deficiencies of the system, and suggests future improvements for an advanced system.

L'Oeil Infrarouge (IR) a été mis au point grâce au support du Secrétariat National Recherche et Sauvetage (NSS). pour améliorer l'efficacité des opérations aériennes de recherche et sauvetage. Le concept de l'œil IR est calqué sur l'œil humain et utilise simultanément deux champs de vue afin d'optimiser l'étendue de surface couverte et la capacité de détection. Deux caméras sont intégrées : la première est utilisée pour la recherche et la détection, avec un champ de 40°, tandis que la seconde possède un champ de 10°, plus étroit pour une plus grande résolution nécessaire à l'identification; ce champ plus étroit est mobile dans le cadre du champ large et asservi à la direction de regard de l'opérateur au moyen d'un système de suivi oculaire. Les images des deux caméras sont fusionnées l'une dans l'autre et affichées simultanément sur un écran CRT à haute résolution, interfacé avec le système de suivi oculaire pour une interaction homme-machine optimale. L'Oeil IR a subi un premier test en vol à bord de l'Avion de Recherche pour les Systèmes Évolués (hélicoptère Bell 412) du Laboratoire de Recherche en Vol du Conseil National de Recherche du Canada. Ce rapport décrit le prototype et l'approche suivie pour sa conception, présente quelques résultats du test en vol, souligne ses forces et ses déficiences, et suggère des amélioration pour un future système plus avancé.

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